Robotic Aircraft Maintenance Activities

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company,
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DoD Weapon System Maintenance and Other Process Improvements Overview

Accomplishments

F-117 Robotic Coating System
Customer: Air Force F-117 SPO
Developed & deployed cost-effective robotic system to apply stealth coating for 50 aircraft fleet

Demilitarization Hazardous Operation Risk Reduction
Customer: Army DAC
Demonstrated automated disassembly of inert 40mm munitions at Army ammunition plant

CVX Trade-off Studies
Customer: Navy CVX PM/LM Moorstown
Recommend manning reduction opportunities for new aircraft carrier under design

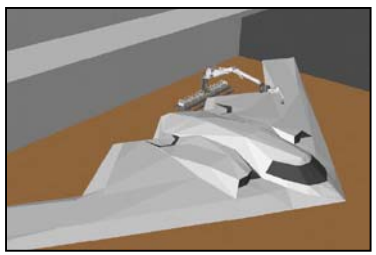
Today

F-22 Robotic Coating Upgrades
Customer: Lockheed Martin, Marietta
Developing & implementing hardware & control improvements to existing robotic coating system

Smart Crane
Customer: Navy NSWC
Demonstrating swing-free ship off-loading with sea-state compensation on Navy transport ship

155 mm Automated Disassembly
Customer: Army DAC
Developing automated system to disassemble projectiles containing grenade & antipersonnel mine submunitions

Over Time, in the Future



B-2 Robotic Coating System
Customer: Air Force B-2 SPO/Northrop Grumman
Develop & deploy cost-effective automated coating system for 20 aircraft fleet

LM/SNL Shared Vision project
Developing automated assembly / disassembly & human motion planner for aircraft logistics & maintenance operations

Advanced Logistical Support Operations
Developing intelligent autonomous robot technologies to transport supplies from warehouses to aircraft

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Outline

- F117 Painting Project
- LARPS22 Modification for F22 Painting
- Flexible Automation study

F-117 Robotic Coating Project

GOOD NEWS…

- **Successful Automation Integration Project**
- **Effectively Reduced Cycle Time and Costs for the Recoating Process**

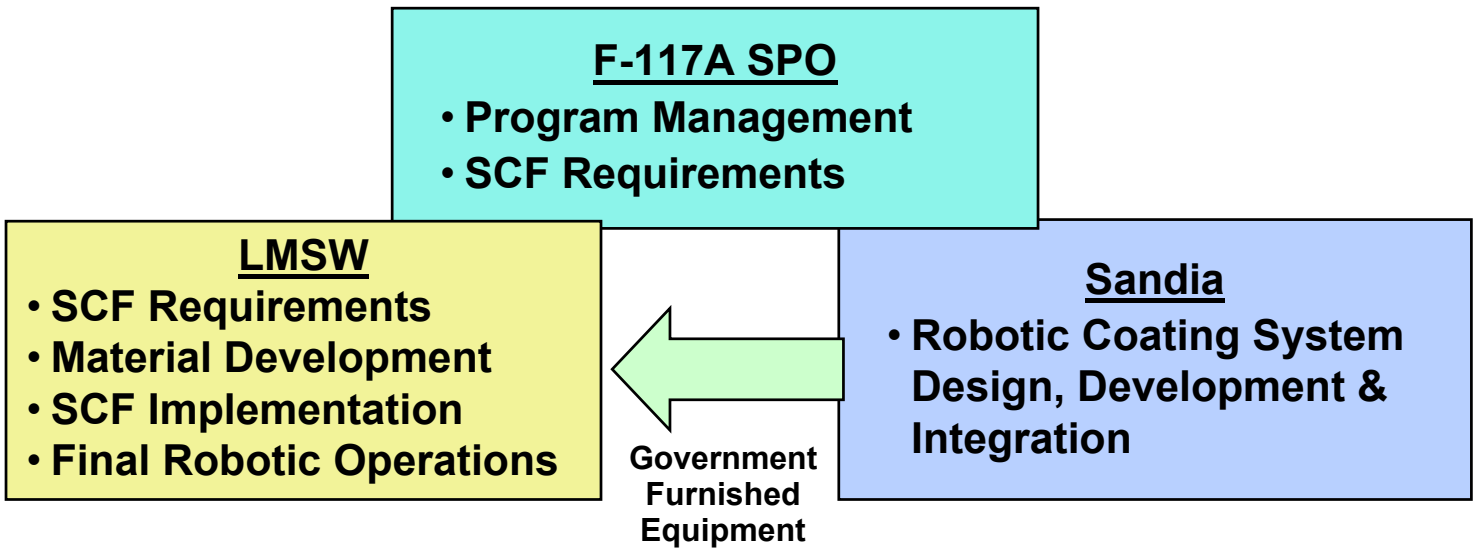
Within Limits…

- **Optimized for Single A/C**
- **Low Utilization of Facility and Automated System**

Desire to explore better ways to take advantage of automation tools and technologies to increase flexibility, utilization and applications to reduce overall weapons sustainment costs

F-117A Robotic Coating System

- Improve the reliability, availability and maintainability of the F-117A Fleet by robotic application of RAM coating
- Supplied to LM Skunk Works as a turnkey system
- Shipped in Aug. 1998; coated first aircraft in Feb. 1999
- First production aircraft coated in March 2000, second in May 2000
- 12 aircraft coated as of April 2001
- 11 aircraft per year production rate



F-117A Robotic Coating Process

- **Locate the aircraft**
  - Vision system finds jack points
  - Relative registration of jet to robot
- **Registration of aircraft facets**
  - Vision finds fiducials around area to be coated
  - Accounts for jet-to-jet variations
  - Generates surface (facet) geometry in robot world
- **On-line Path Generation**
  - Plans a task path (based on painting parameters)
  - Plans a robot path to achieve the task path
  - Uses collision avoidance to plan the path
- **Independent Path Verification**
  - Collision detection is performed in the model world on the generated path
  - Robot is run in simulation
  - Optionally, the model robot and path are viewed
- **Paint**

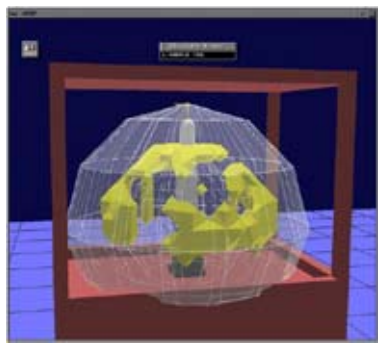
F-117A Robotic Coating System Development

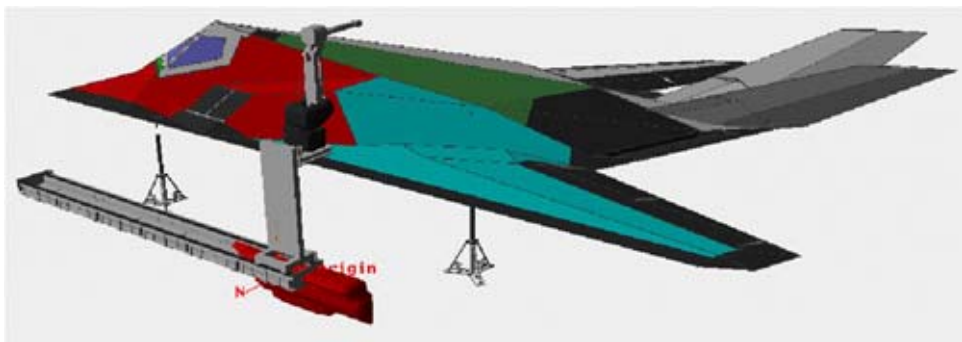
Development Laboratory

Simulation

Enabling Technologies - Reachability Analysis

- This Sandia technology determines the working volume for an integrated system (vehicle, manipulator, and tooling) from a given location
  - Analysis based on manipulator joint lengths and motion limits, tool design, etc.
  - Exceptionally useful to evaluate system configuration and tooling design choices for systems with greater than five degrees of freedom
  - Useful for showing an operator the optimal location to position a vehicle so the robot can perform a desired set of tasks





F-117A Robotic Coating System

- 12 aircraft coated as of April 2001
- Results of robotic coating system for RAM
  - Uniform build
  - Excellent finish
  - Eliminates rework
  - Reduced RCS and signature
  - Reduction in process time, from 8+ days to 4+ days

Large Aircraft Robotic Paint System (LARPS) Development for F-22 Painting

- Modifications for Class I Div I hazardous environment operation
- Conversion from paint stripping to coating
- Improved motion control

Large Aircraft Robotic Paint System (LARPS) Development for F-22 Painting

LARPS

- Waterjet-based depainting
- Tinker AFB

- Mods at Sandia LARPS22

Upgrade to LARPS22

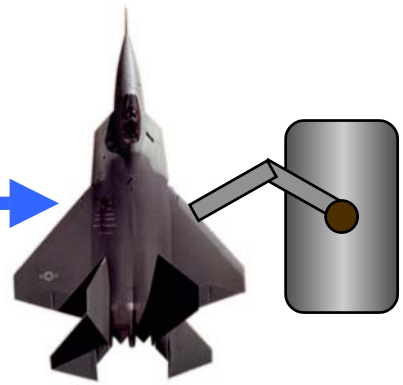
F-117A Technology Leverage

- Automated Path Planning
- Reachability analysis
- Collision avoidance & check
- Intuitive user control
- Modeling & simulation
- Targeting & registration

CASPER

- First Generation F-22 painting robot
- LMAS, Marietta, GA

Upgrade to CASPER+



Only Two of a Kind

LARPS at TAFB

Casper at LMAC

Conversion to LARPS22 - Summary

- LARPS shipment from TAFB to Sandia
- Column size reduction for L-64, Phase II facility
- Umbilical boom design/fabrication
- Revision to umbilical boom design for 2-robot workcell
- Removal of LARPS paint stripping systems
- Wiring and systems modifications for paint application
- Re-assembly of LARPS22 at Sandia
- Upgrade of column, AGV, and SCARA purge systems
- Conversion of AGV, column, and SCARA to Class I, Div I standards
- Programming, system controls and robot path validation on LARPS robot arm
- Programming and system control of AGV
- Systems testing
- Evaluations of motion control performance
- Development of motion control improvements

Motion Comparison

Example: Vertical Stabilizer Coating Path

Original

- Path tag points sent to robot controller
- Robot controller generates joint values for 3DOF large SCARA and 6DOF P-156 as 2 separate robots
- Joint values sent to servo drivers
- Servos can not maintain acceleration profiles required

Optimized

- Path tag points sent 9 DOF Sandia software
- Sandia software uses coating rules to generate joint values for system as one 9 DOF robot.
- Joint values sent to servo drivers bypassing robot controller kinematics
- Success

Installation at LMAC, Marietta GA

Flexible Aircraft Maintenance Facility (FAMF) Project Overview

- **Sandia Robotics Center Research and Development Project**
  - Study military aircraft maintenance needs for automation
  - Identify automation/integration opportunities
  - Evaluate and develop flexible automation design tools
- **Focus**
  - Multiple aircraft groups
  - Multiple maintenance processes
- **Goal**
  - Provide automation design tools for flexible maintenance facilities
  - Demonstration of technology
- **Expected Benefits**
  - Increased utilization of facilities and capital equipment
  - Reduced cost in automation programming
  - Reduced maintenance and operations costs

FAMF 3-year Project Plan

- **Phase 1**
  - Gain an understanding of aircraft maintenance operations
  - Visit maintenance depots and understand critical needs
  - Identify processes for potential flexible maintenance automation technologies
- **Phase 2**
  - Identify technology and integration needs
  - Identify automation design tool needs
  - Begin development of flexible design tools
- **Phase 3**
  - Apply design tools to a demonstration
  - Select a maintenance task/process for technology development and pilot demonstration

Visits to DoD Depots

- **Identify and discuss DoD aircraft maintenance needs**
  - **Critical process needs**
  - **Needed automation technologies**
  - **Facility architecture**
- **Key questions:**
  - **Which maintenance processes are key cost and schedule drivers? (expensive, dangerous, difficult, prone to injury, manpower intensive, etc.)**
  - **What processes would benefit from automation (new or improved)?**
  - **How can automation be utilized more effectively?**
  - **What are the problems with current automation?**
  - **What would you do differently if you had a clean start…a "greenfield" approach?**

Automation & Robotics for Large Structures
Some Examples

- Automated Aircraft Rework System (wings)
- Robotic Gantry Ultrasonic Scanner
- Robotic FlashJet® for component paint removal
- FlashJet® depaint head on mobile platform
- Laser automated decoating system
- Robotic media blast depaint system
- Robotic painting systems

Preliminary Observations and Trends

- Automation drivers are environmental, productivity, quality, manpower
- Programmatic/political drivers: grouping for automation will be by depot assignment, not just by size and type
- Automation trend toward even more aircraft-type-specific workcells
- Facility utilization is generally high
- Improvements are needed for use of depaint systems on large aircraft
- Interest in registration/orientation of the robot to aircraft

Preliminary Observations and Trends

- Interest in co-locating paint stripping and corrosion control operations
- Interest in improving depaint coverage
- Modernization requests may be perceived to expose a weakness
- Workforce issues:
  - Operator training, job grade, manpower levels, system maintenance, programming
- Challenges to reduce process TAT, increase ROI
- Concern that automation systems do not pay for themselves - making a business case is essential

Applicable Technologies

- **Reachability Analysis Software**
  - **Use of 3D models to determine dexterous working volume and optimize workcell layout**
  - **Benefits**
    - **Optimized robot position**
    - **Reduced setup and programming time**
    - **Increased coverage**
    - **Reduced process duration**
    - **Improved process quality by improved robot motion performance**
  - **Applies to**
    - **Coating/decoating**
    - **Sealing**
    - **Inspection**
    - **Fastener removal/insertion**

Applicable Technologies

- **Automated Path Generation**
  - **Automated generation of task paths and robot motions from 3D models and process constraints**
  - **Benefits:**
    - **Reduced programming time**
    - **Optimized robot motion**
    - **Minimized process cycle time**
  - **Applies to:**
    - **Coating/decoating**
    - **Sealing**
    - **Inspection**

Applicable Technologies

- Sensor-driven contact operations
  - e.g. seam characterization and location
  - Sensor-based robot motions with feedback
  - Process monitoring and feedback
    - e.g. caulking, sealing